1528-3542/18/$12.00 http://dx.doi.org/10.1037/emo0000388

Auditory Affective Processing Requires Awareness

Mikko Lähteenmäki and Jaakko Kauramäki
Aalto University

Disa A. Sauter
University of Amsterdam

Lauri Nummenmaa
Turku PET Centre, Turku, Finland, and University of Turku

Recent work has challenged the previously widely accepted belief that affective processing does not require awareness and can be carried out with more limited resources than semantic processing. This debate has focused exclusively on visual perception, even though evidence from both human and animal studies suggests that existence for nonconscious affective processing would be physiologically more feasible in the auditory system. Here we contrast affective and semantic processing of nonverbal emotional vocalizations under different levels of awareness in three experiments, using explicit (two-alternative forced choice masked affective and semantic categorization tasks, Experiments 1 and 2) and implicit (masked affective and semantic priming, Experiment 3) measures. Identical stimuli and design were used in the semantic and affective tasks. Awareness was manipulated by altering stimulus-mask signal-to-noise ratio during continuous auditory masking. Stimulus awareness was measured on each trial using a four-point perceptual awareness scale. In explicit tasks, neither affective nor semantic categorization could be performed in the complete absence of awareness, while both tasks could be performed above chance level when stimuli were consciously perceived. Semantic categorization was faster than affective evaluation. When the stimuli were partially perceived, semantic categorization accuracy exceeded affective evaluation accuracy. In implicit tasks neither affective nor semantic priming occurred in the complete absence of awareness, whereas both affective and semantic priming emerged when participants were aware of the primes. We conclude that auditory semantic processing is faster than affective processing, and that both affective and semantic auditory processing are dependent on awareness.

Keywords: auditory awareness, affective recognition, affective priming

Multiple theories of emotional processing suggest that affective processing precedes most stages of perceptual and cognitive processing (Murphy & Zajonc, 1993; Zajonc, 1980), and can even operate independently of awareness (LeDoux, 1998; Tamietto & De Gelder, 2010). Such accounts propose that during phylogenesis, the evolutionary pressure for rapid responses to survival-salient stimuli was so great that specialized mechanisms for detecting these stimuli developed. To further maximize the organism's chances of survival, these mechanisms evolved to operate faster than conscious perception, which takes several hundred milliseconds to build (Koch, 2004). A subset of these models further assume that nonconscious processing of emotion involves a separate subcortical pathway that operates independently from the cortical mechanisms associated with conscious perception (Tamietto & De Gelder, 2010).

Previous studies on nonconscious affective processing in humans have focused almost exclusively on the visual system, even though a substantial amount of the neurobiological evidence for nonconscious affective processing in fact originates from auditory fear conditioning studies in animals (LeDoux, 1998; Quirk, Repa, & LeDoux, 1995). This is a critical discrepancy, as the existence of a separate "fast" affective pathway in the visual system has recently been challenged on both neuroanatomical (Pessoa & Adolphs, 2010) and computational (Cauchoix & Crouzet, 2013) grounds, thus questioning how the brain could accomplish nonconscious visual affective processing in the first place. In line with this, accumulating evidence from human behavioral studies also questions the possibility of nonconscious affective processing in the visual domain (see meta-analysis in Lähteenmäki, Hyönä, Koivisto, & Nummenmaa, 2015; Hedger, Adams, & Garner, 2015).

It is however noteworthy that the aforementioned computational and neuroanatomical constraints do not apply to auditory affective

Mikko Lähteenmäki and Jaakko Kauramäki, Department of Neuroscience and Biomedical Engineering, School of Science, Aalto University; Disa A. Sauter, Department of Social Psychology, University of Amsterdam; Lauri Nummenmaa, Turku PET Centre, Turku, Finland, and Department of Psychology, Turku University.

This research was supported by the aivoAALTO Project at Aalto University, Emil Aaltonen Young Researcher Grant to Mikko Lähteenmäki, the Academy of Finland (Grants 251125, 265917, and 294897 to Lauri Nummenmaa), the European Research Council (Starting Grant 313000 to Lauri Nummenmaa), and the Netherlands Organisation for Scientific Research (Grant 275-70-033 to Disa A. Sauter).

Correspondence concerning this article should be addressed to Mikko Lähteenmäki, Department of Neuroscience and Biomedical Engineering, School of Science, Aalto University, FI-00076 Aalto, Espoo, Finland. E-mail: mikko.2.lahteenmaki@aalto.fi

processing. Auditory affective information is accessible already from features processed by subcortical regions, and the necessary connections that would enable affective responses without cortical involvement, and without awareness, are present in the subcortical auditory system (Campeau & Davis, 1995; Doron & LeDoux, 1999; Keifer, Gutman, Hecht, Keilholz, & Ressler, 2015). Therefore, even though nonconscious affective processing may be impossible in the visual domain, serious consideration must be given to the possibility that auditory affective processing could occur in the absence of awareness. However, this hypothesis currently lacks direct empirical support in humans. Moreover, previous studies documenting nonconscious processing of affect (e.g., Hermans, Spruyt, De Houwer, & Eelen, 2003; Murphy & Zajonc, 1993; Sweeny, Grabowecky, Suzuki, & Paller, 2009) have not contrasted affective with semantic processing to determine whether semantic processing would occur under similar constraints, thus, their findings cannot be taken to support the notion that affective processing is "special" in terms of independence from awareness. Finally, previous studies have largely treated consciousness as an all-or-none phenomenon, and used the discrimination threshold as criterion for awareness. Yet, recent evidence indicates that consciousness is graded (Pessoa, 2013), and that subjective experience of sensory information—consciously detecting the presence of a stimulus—can occur even when the stimulus cannot be consciously discriminated. Any processing that occurs under such conditions is thus not taking place in the absence of consciousness. Consequently, to accurately test for nonconscious processing, the detection threshold should be used as criterion for consciousness.

Here, we test the possibility of nonconscious auditory affective and semantic processing in three experiments by contrasting affective and semantic categorization of emotional vocalizations under different levels of awareness, using explicit two-alternative forced choice (2AFC) affective and semantic categorization tasks (affective and semantic categorization; Experiments 1 and 2), and implicit (affective and semantic priming; Experiment 3) categorization as indices of affective and semantic processing.[1]

Can Emotional Processing Occur Without Awareness and Precede Semantic Processing?

The temporal relationship between affective and semantic processing is relevant with respect to how quickly these kinds of information can modulate information processing in the brain, and whether affective processing can influence decision-making prior to cognitive analysis. Moreover, the question of whether affective processing can be carried out in the absence of awareness or with more limited resources than other cognitive operations has been one of the central theoretical debates in cognitive psychology for over two decades, and also pertains to the neural and cognitive models of awareness. Models of emotional processing propose that affective recognition is fast, effortless and automatic (Bargh, 1997), precedes semantic categorization (Murphy & Zajonc, 1993; Zajonc, 1980), and can be carried out independently of awareness (Tamietto & DeGelder, 2010). Yet, recent studies have shown that in the visual domain, affective categorization in fact requires stimulus awareness (Hedger, et al., 2015; Lähteenmäki et al., 2015; Pessoa, Japee, & Ungerleider, 2005; Pessoa, Japee, Sturman, & Ungerleider, 2006) and can only be accomplished after semantic categorization (Nummenmaa, Hyönä, & Calvo, 2010). These findings support semantic rather than affective primacy, and show that visual affective processing is dependent on awareness.

A critical assumption of affective primacy models is that affective processing does not require detailed perceptual processing, whereas semantic processing and conscious perception do. Based on this assumption, a widely accepted "two-pathway" model (e.g., LeDoux, 1998; Tamietto & DeGelder, 2010) posits that fast nonconscious affective processing can be carried out by a phylogenetically old extrageniculastriate subcortical pathway that projects from the retina through the superior colliculus and pulvinar to the amygdala (LeDoux, 1998). In contrast, conscious processing is thought to depend on slower cortical processing along the ventral visual stream that starts from the primary visual cortex (designated V1) and projects though V2 and V4 to the inferotemporal cortex, which in turn provides connections to the amygdala (Milner, Goodale, & Vingrys, 2006).

Importantly, abnormal functioning of the pathways proposed to mediate nonconscious emotional processing have also been suggested to underlie several psychiatric conditions such as posttraumatic stress disorder, mood and anxiety disorders (Öhman & Mineka, 2001). Thus, resolving the debate over the independence versus dependence of affect on awareness has clinical as well as theoretical implications. Yet, the critical studies for settling these issues have only recently been carried out in the visual processing domain (Cauchoix & Crouzet, 2013; Lähteenmäki et al., 2015; Nummenmaa et al., 2010; Pessoa, 2005; Pessoa et al., 2005) and remain unresolved for other sensory modalities. To our knowledge there are no previous studies testing whether nonconscious categorization of biologically relevant affective signals is possible in the human auditory system, and whether both affective and semantic auditory information processing are subject to similar constraints imposed by awareness.

Evidence for Affective Auditory Processing in the Absence of Awareness

Although the existence of nonconscious affective processing of visual information has been shown to be unlikely (see above), three lines of evidence speak for the possibility of nonconscious affective processing in the auditory domain. First, within both the auditory and visual systems, conscious cognitive processing of sensory information requires cortical processing (Koch, 2004; Tong, 2003; Wiegand & Gutschalk, 2012), whereas affective evaluation is thought to require the stimulus information to have access to the amygdala (Adolphs, Russell, & Tranel, 1999; Gosselin, Peretz, Johnsen, & Adolphs, 2007; Phelps & LeDoux, 2005; Zald, 2003). Consequently, in both systems damaging the sensory cortices impairs awareness for that modality (Özdamar, Kraus, & Curry, 1982; Tong, 2003), while damage to the amygdala impairs affective recognition for both modalities (Adolphs, Tranel, Damasio, & Damasio, 1994; Scott et al., 1997). Contrary to what is postulated by

[1] Note that that the terms *semantic task* and *affective task* do not refer to stimulus properties or linguistic semantics, but to the cognitive or emotional process of categorizing the stimulus. These terms accord with established terminology in the field (e.g., Calvo & Nummenmaa, 2007; Lähteenmäki et al., 2015; Nummenmaa et al., 2010).

the two-pathway model, visual sensory information in fact reaches the amygdala only after extensive cortical processing, and there is no evidence for the existence of a functional subcortical route between the retina and the amygdala that would bypass the visual cortex (Pessoa & Adolphs, 2010).

In contrast, direct projections from the auditory medial geniculate nucleus of the thalamus to the amygdala have been documented in mice and humans (Keifer et al., 2015). Thus, at least on the neuroanatomical level the auditory system provides the necessary circuits for performing affective evaluation in the absence of awareness. Moreover, lesion studies have demonstrated that even after the complete destruction of the primary auditory cortex (PAC), responses to environmental sounds or sudden acoustic stimuli may be preserved (Hain & Micco, 2003), demonstrating that the subcortical auditory system can process auditory information sufficiently to influence survival responses in the absence of PAC.

Second, the computational requirements for recognizing emotional stimulus content are different within the visual and auditory sensory modalities. Within the visual domain emotional stimulus information is only accessible from high-level visual representations encoded following object recognition, and the level of selectivity and invariance required for real-world visual recognition are not found in the subcortical visual system (Cauchoix & Crouzet, 2013). In contrast, auditory emotional information is already represented in low-level sensory features, as evidenced by the fact that emotions can be classified from speech using frequency and energy information (El Ayadi, Kamel, & Karray, 2011). Thus, recognition of auditory emotional cues likely has significantly reduced computational demands compared to visual affective recognition. Importantly, the auditory thalamus encodes pitch structure information (Scott, 2005) and displays selectivity for combinations of frequencies (Olsen & Suga, 1991). Consequently, the subcortical auditory system meets both the anatomical and computational requirements for performing emotional recognition independently from cortical involvement, whereas as the subcortical visual system does not.

Third, the animal models that constitute the original foundation for the neurobiological theories of nonconscious affective processing are primarily based on auditory fear conditioning studies in rats (LeDoux, Sakaguchi, & Reis, 1984; Quirk et al., 1995; Schafe & LeDoux, 2000). These studies have established that lesions on the rat auditory cortex do not affect the magnitude of the conditioned fear response, whereas lesions along medial geniculate nucleus of the thalamus suppress both autonomic and somatomotor emotional conditioned responses. Consequently, projections between the auditory thalamus and the amygdala mediate the processing of emotional information in auditory stimuli independently of PAC (Bordi & LeDoux, 1994). In contrast, there is no evidence for a functional subcortical pathway supporting affective processing in the human visual system (Pessoa, 2005, 2013), and anatomical studies indicate that the existence of such a link in primates is unlikely (Imura & Rockland, 2006) In sum, if nonconscious affective processing indeed exists in humans, it is more likely to be found within the relatively unexplored auditory than in the visual system where contradictory evidence has been accumulating.

The Current Study

Here we determined whether auditory affective and semantic processing can take place in the absence of auditory awareness using explicit and implicit categorization to index nonconscious processing. An important limitation of these behavioral measures is that our findings are constrained to affective or semantic processing that can modulate behavior. To verify whether some form of affective or semantic processing insufficient to influence behavior indeed occurs in the brain, eletrophysiological and brain imaging measures should be conducted to complement the present experiments. In the present study the term *auditory awareness* is used to refer to the subjective experience of hearing, and the terms consciousness and awareness are used as synonyms. This series of experiments is built on four methodological considerations to allow for strict comparisons between conscious versus nonconscious affective and semantic processing. First, we contrasted affective and semantic auditory categorization at different levels of awareness using the same stimuli in affective and semantic categorization tasks. This allowed us to test the hypothesis that auditory affective processing is "special" in terms of speed or independence from awareness. Second, we measured the participants' subjective level of awareness on each trial using the 4-point Perceptual Awareness Rating Scale (PAS; Ramsøy & Overgaard, 2004) to account for intrasubject fluctuations in detection sensitivity as well as trial-to-trial variation in level of arousal and attention allocation (Macmillan & Creelman, 2004; Ramsøy & Overgaard, 2004). Third, we applied signal detection theory to determine each subject's capability for detecting the masked stimuli, to ensure that intersubject variability in detection sensitivity was accounted for. Fourth, we utilized both direct (2AFC categorization) and indirect (masked priming) measures of affective processing to ascertain our analyses were not limited to explicit reporting in a conscious decision making task.

Experiment 1

In Experiment 1, we compared explicit affective and semantic categorization of consciously perceived and nonconscious emotional auditory stimuli. To ensure that affective categorization was not confounded with linguistic processing, we used biologically relevant nonverbal emotional vocalizations as stimuli. The participants were presented with emotional vocalizations that were suppressed by continuous auditory masking; conscious perception of the stimuli was then manipulated by varying the target-mask signal-to-noise-ratio. The target stimuli were presented at a random moment embedded within a continuous overlapping mask, so that participants could not focus temporal attention on the target to increase the likelihood of conscious percept. To minimize categorization errors from anticipatory responses, the participants were prompted to respond only after both the target and mask had been presented. This also ensured that the target stimuli had always been fully presented before the participants responded.

Participants performed 2AFC affective evaluation (pleasant vs. unpleasant) of the stimuli in one block and 2AFC semantic categorization (male vs. female actor) in the other. All stimuli could be categorized along both their affective and semantic dimensions; thus, the stimulus sets were identical in both blocks. To measure the participants' conscious perception of the stimuli, participants rated their level of stimulus awareness on each trial using the

4-point PAS (Ramsøy & Overgaard, 2004), which allows us to contrast affective and semantic processing separately for below-detection and below-discrimination threshold stimuli. Data were analyzed both as a function of masking strength and trial-wise as a function of the subjective awareness ratings.

Method

Participants. Twenty-four university students (11 females and 13 males, age 20–31 years, $M_{age} = 24$ years) participated in the experiment. All participants had normal hearing and normal or corrected-to-normal vision based on self-reports, and gave informed consent prior to participating in the study. Sample size was selected according to power calculations based on mean effect size of nonconscious affective processing ($r = .62$) in previous experiments (See meta-analysis in Lähteenmäki et al., 2015), which indicate that at alpha level of .05, sample sizes of 24 is sufficient for establishing the predicted effect with the actual power exceeding 90%.

Stimuli and apparatus. The stimuli were 80 nonverbal vocalizations of positive (20 amusement, 20 triumph) and negative (20 disgust, 20 fear) emotions with 10/10 male/female tokens in each category produced by two male and two female native English speakers and lasting <2 s each (Sauter, Eisner, Ekman, & Scott, 2010). To ensure that Finnish listeners could reliably recognize both the emotion and the gender from the tokens, we first obtained normative data for the whole unmasked stimulus set of Sauter and colleagues (10 emotions, 26 tokens per category) from 155 Finnish university students. Using an online rating tool, participants performed 2AFC categorization of gender and 10AFC categorization of emotion in addition to rating the stimuli according to their valence (positive–negative) and arousal (high–low) dimensions on a 9-point scale. Stimuli were presented in a random order, and participants had the option of performing the task over multiple sessions or to categorize only a subset of the stimuli. On average, ratings from 37 subjects (range = 26–46) per stimulus were acquired. The normative data (see Figure 1) showed that recognition of unmasked stimuli was significantly above chance level for both gender (chance level = .50) and emotion (chance level = .10) for all stimulus categories. Two positive (amusement, triumph) and two negative (disgust, fear) high-arousal ($M_{arousal} > 5$) emotion categories with the highest emotion recognition scores (>.75) were selected for use in the experiments. Normative data indicated that these stimuli differed significantly in terms of valence, ($M_{positive} = 6.76$, $SD_{positive} = .73$, $M_{negative} = 2.55$, $SD_{negative} = .63$), $t(101) = 31.39$, $p < .001$, $r = .952$, indicating that they were perceived as positive and negative as intended.

In addition, 10 natural informational noise masks (4 s each) were constructed by mixing together 50 stimuli sampled randomly from all emotion categories with random onsets. This produced unintelligible nonemotional sounds. Pilot testing confirmed that these stimuli had superior masking power on the target stimuli compared to white or pink noise.[2] All auditory stimuli were sampled at 44100 Hz with 16-bit resolution. Stimuli were delivered via headphones and participants responded via key press.

Procedure. Figure 2 summarizes the experimental design. Each trial began with a fixation cross displayed at the center of the screen for 1 s. This was followed by a 4-s randomly selected noise mask. The target sound was presented following a random 1- to 2-s delay from mask onset; the target was thus always temporally completely embedded within the mask. Following mask offset, a question mark on the screen prompted the subject to respond. To manipulate target audibility, target amplitude was attenuated according to three predetermined levels (strong, moderate and weak masking strength). To control for variation in audibility due to differences in low-level features between categories, individual attenuation levels were determined in piloting for each stimulus category by iteratively increasing attenuation power for each masking strength until a desired level was reached. To maximize the potential of eliciting nonconscious processing, desired attenuation level for strong masking was determined as minimum amount sufficient for maintaining conscious detection at chance level. For moderate masking, the desired level was set at equal proportions of below detection, above detection but below discrimination, and above discrimination level responses. For weak masking, desired attenuation level was set at > .50 completely aware responses. The actual attenuation factors used in the experiment were (a) Amusement, weak: −5 dB, moderate: −12 dB, strong: −18 dB; (b) Triumph, weak: −0 dB, moderate: −7 dB, strong: −11 dB, (c) Disgust, weak: −5 dB, moderate: −10 dB, strong: −16 dB; (d) Fear: weak: −0 dB, moderate: −7 dB, strong: −11 dB.

Each stimulus was presented once at each masking level in a random order. In addition, the experiment included 20% catch trials, in which only the noise mask was presented. On each trial, the participants performed a categorization task (unpleasant vs. pleasant or male vs. female, depending on the block) followed by rating of stimulus awareness on a 4-point PAS-scale (1 = *I did not hear the target at all*; 2 = *I heard something, but do not know what it was*; 3 = *I heard something, and think I can determine what it was*; 4 = *I heard the target clearly*). Previous studies have confirmed that trial-wise PAS does not confound with performance in the primary task (Lähteenmäki et al., 2015). The next trial began after the participant gave their response to the PAS. In the categorization task, they were instructed to use their left and right index fingers; the response buttons were counterbalanced across participants.

The experiment involved two blocks of 300 trials, with identical trial structures and stimuli. In the *affective block,* participants' task was to determine the affective valence (pleasant vs. unpleasant) of the stimulus as quickly and accurately as possible, whereas in the *semantic block*, their task was to decide whether the speaker was male or female. Response accuracies and latencies were measured. The order of the tasks was counterbalanced across participants. The participants were told that each trial would consist of the mask and a target sound played at some point during the mask presentation. They were instructed to ignore the mask and focus on categorizing the target as accurately as possible. Before the experiment the participants were familiarized with the response protocol and before each stimulus block they performed a short practice session consisting of 20 trials.

[2] At the strongest masking attenuation levels used in the experiment, white- and pink-noise masks still produced above chance-level detection, in contrast to chance-level detection for natural informational noise masks.

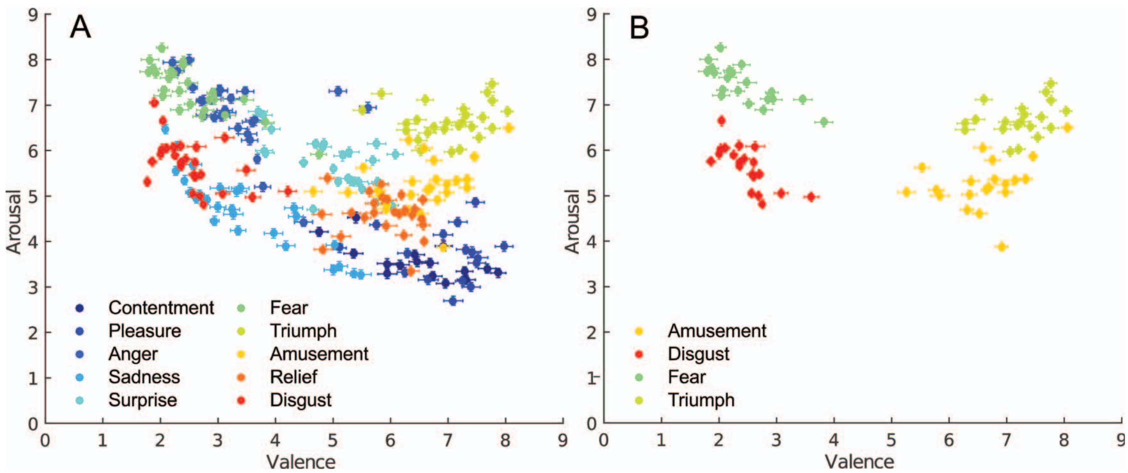

Figure 1. Normative ratings for valence and arousal of (A) all tokens in the Sauter et al. (2010) set and (B) tokens used in Experiments 1 and 2. Error bars represent the 95% confidence interval for recognition of emotional category (*x* axis) and gender (*y* axis).

Results

The categorization data were first analyzed as a function of masking strength (see Figure 3). One-sample *t* tests were used to test whether categorization performance in the affective and semantic tasks was above chance level at each masking level. In this and subsequent experiments, Greenhouse–Geisser correction was applied to the degrees of freedom and the corrected *p* value is reported if the sphericity assumption was not met. In the affective task, performance was at chance level under the strong masking condition, $t(23) = 1.213$, $p = .237$, $r = .244$, but above chance under moderate and weak masking conditions, $ts(23) > 10.490$, $ps < .001$, $rs > .908$. In the semantic task, performance was above chance level for all masking conditions, $ts(23) > 2.348$, $ps < .026$, $rs > .439$. Accuracy scores were then subjected to a 2 (Task: affective vs. semantic) × 3 (Masking Strength: weak vs. moderate vs. strong) analysis of variance (ANOVA), which yielded a main effect of masking strength, $F(2, 46) = 212.46$, $p < .001$, $\eta_p^2 = .902$, and an interaction of Task × Masking Strength, $F(2, 46) = 5.62$, $p = .009$, $\eta_p^2 = .196$. Accuracies were highest under weak masking (.78 semantic, .83 affective) and lowest under strong masking (.53 semantic, .52 affective). Decomposing the interaction did not reveal any significant differences between the tasks after correcting for multiple comparisons with the Bonferroni procedure. Main effect of categorization task (emotional vs. semantic) was not significant, $F = .001$.

Next, discriminability indices (d') for conscious detection of the stimuli were calculated from the awareness rating responses for target and catch trials. Ratings higher than 1 in PAS were defined as hits in stimulus-present trials and as false alarms in catch trials. Thus, the d' indexes the participants' ability to consciously discriminate between trials with and without the target stimulus. The d' values for stimuli under strong masking condition (.37 affective; .51 semantic) were significantly higher than zero in both tasks, $ts(23) > 4.82$, $ps < .001$, $rs > .709$, indicating that the participants were at least partly aware of the stimuli on some trials even when strong masking was applied.

Consequently, the data were next analyzed as a function of the PAS awareness rating responses. One sample *t* tests showed that, in the complete absence of awareness (awareness rating response 1), performance was at chance level in both tasks, $ts(23) < .978$, $ps > .338$, $rs < .201$, but significantly above chance level when participants were partially or completely aware of the stimuli, $ts(23) > 5.66$, $ps < .001$, $rs > .762$. Accuracies were then subjected to a 2 (categorization task) × 4 (level of awareness) ANOVA, which revealed a main effect of level of awareness, $F(3, 69) = 88.33$, $p < .001$, $\eta_p^2 = .793$. There were no other significant

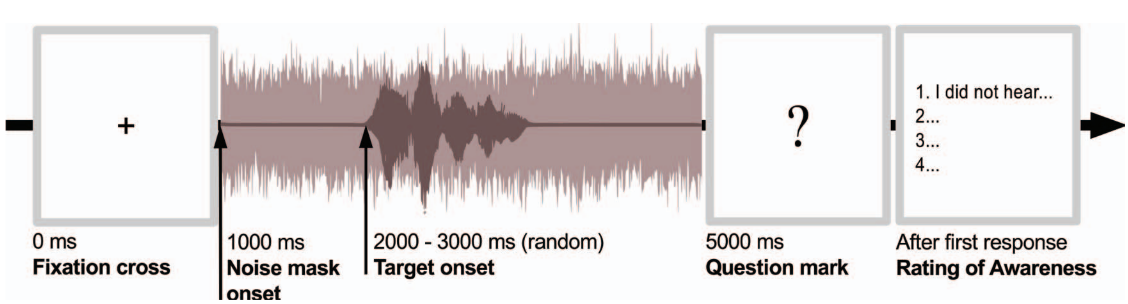

Figure 2. Trial structure in Experiment 1. Event times indicate the onset of each event relative to the beginning of the trial. See the online article for the color version of this figure.

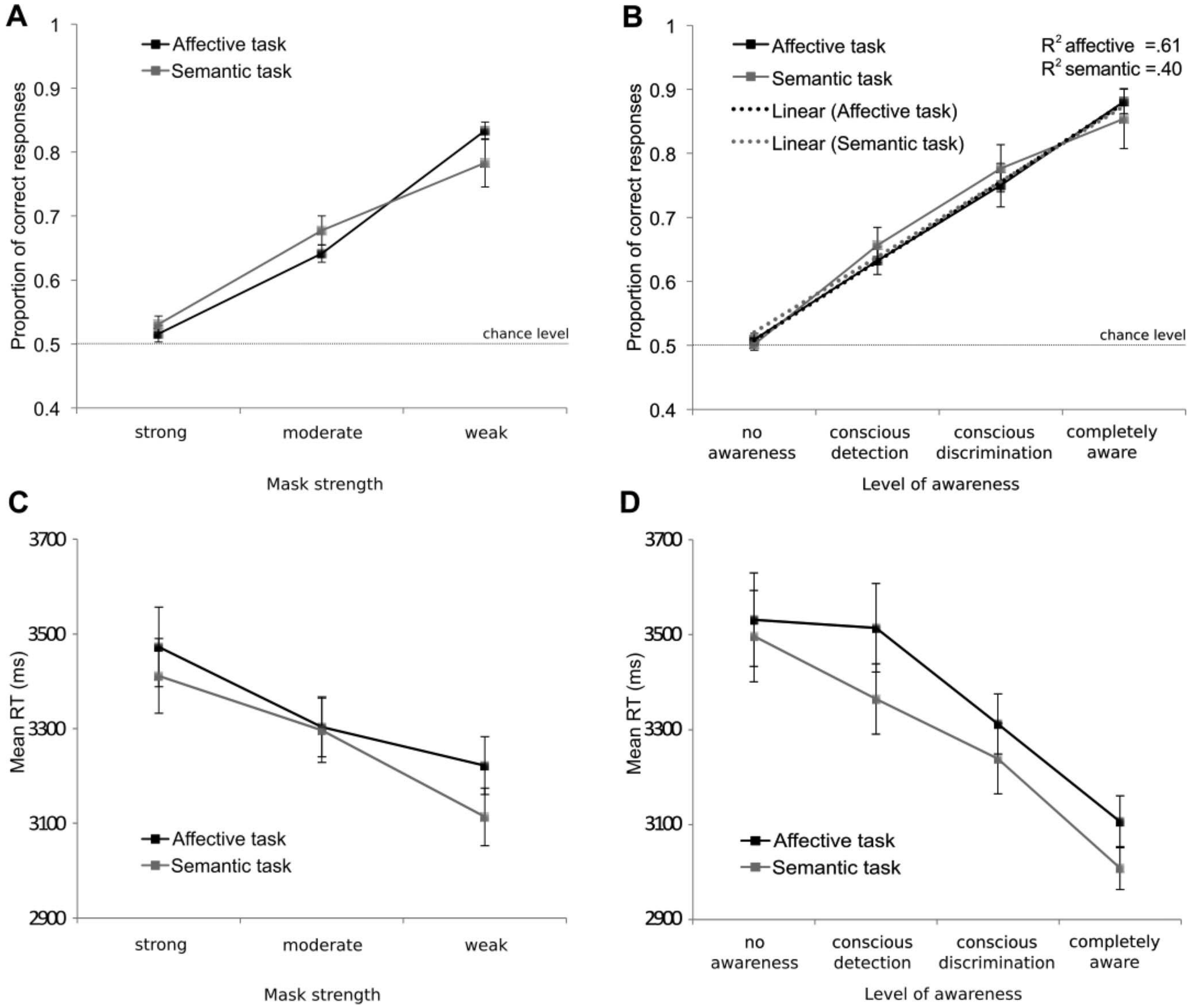

Figure 3. Means and standard errors for response accuracies and reaction times (RTs) in Experiment 1. (A) Semantic and affective categorization accuracies as a function of mask strength. (B) Categorization accuracies as a function of subjective level of awareness. (C) Categorization RTs as a function of mask strength. (D) RTs as a function of level of awareness.

effects or interactions, *F*s $<$ 1.12. In both tasks, performance improved at higher levels of awareness (no awareness: .50 semantic, .51 affective; consciously detected: .65 semantic, .63 affective; consciously discriminated: .77 semantic, .75 affective; completely aware: .85 semantic, .88 affective). Linear regression analysis was conducted to determine the degree to which accuracy can be predicted from subjective level of awareness. Level of awareness significantly predicted accuracy in affective, β = .12, $t(94)$ = 12.21, $p < .001$, and semantic, β = .12, $t(94)$ = 7.96, $p < .001$, tasks as well as explained a significant proportion of variance in both affective, R^2 = .609, $F(1, 94)$ = 149.0, $p < .001$, and semantic, R^2 = .396, $F(1, 94)$ = 63.4, $p < .001$, tasks.

As participants responded only after mask presentation had ended, available processing time between stimulus presentation and response was increased considerably, making reaction time (RT) data difficult to interpret. Yet, as the affective primacy hypothesis specifically predicts that the RTs should be faster for affective versus semantic processing, we analyzed the RT data as well. The 2 (Task: affective vs. semantic) $\times$ 3 (Masking Strength: weak vs. moderate vs. strong) ANOVA on RTs produced a main effect of masking strength, $F(2, 46)$ = 4.59, p = .32, η_p^2 = .166, and an interaction of Task $\times$ Masking Strength, $F(2, 46)$ = 9.81, p = .009, η_p^2 = .299. In both the affective and semantic tasks RTs decreased with each decrease in masking strength (strong: 3,442 ms; moderate: 3,300 ms; weak: 3,167 ms). Decomposing the interaction did not reveal any differences between affective and semantic tasks at any mask strength, *t*s(23) $<$ 1.44, *p*s $>$ .163, *r*s $<$ .288. The corresponding 2 (Categorization Task) $\times$ 4 (Level of

Awareness) ANOVA on RTs revealed a main effect of level of awareness, $F(3, 69) = 11.54$, $p < .001$, $\eta_p^2 = .334$, and task, $F(3, 69) = 18.24$, $p < .001$, $\eta_p^2 = .442$. Affective and semantic RTs decreased with each increase in awareness (no awareness: 3,514 ms; conscious detection: 3,439 ms; conscious discrimination: 3,275 ms; completely aware: 3,057 ms), and overall RTs were significantly faster for semantic versus affective categorization (semantic: 3,277 ms; affective: 3,366 ms). There were no other significant effects or interactions, $Fs < 2.52$.

Discussion

Experiment 1 established that affective and semantic categorization of auditory information depends on awareness. In both affective and semantic tasks, performance was considerably above chance level (.50) under weak and moderate masking. Under strong masking performance was above chance level in the semantic task, and a corresponding but weak trend was observed in the affective task. Yet, signal detection analysis revealed that the participants could consciously detect the stimuli on some trials in both the semantic and affective conditions even when strong masking was used to suppress awareness. Subsequent analyses based on the trial-wise awareness ratings showed that when participants had no conscious percept of the stimuli, their performance was at chance level in both the affective and semantic task. However, when participants were even marginally aware of the stimuli, both semantic and affective categorizations were performed above chance level, and performance in both tasks increased linearly as a function of the level of awareness. Importantly, participants were able to categorize stimuli along both the affective and semantic dimensions already when they could detect the mere presence of the stimulus, even though they could not consciously discriminate what the stimuli were. Such semantic and affective categorization under partial stimulus awareness accords with recent studies of visual awareness and visual recognition (Grill-Spector & Kanwisher, 2005; Lähteenmäki et al., 2015), which have shown that in the visual domain, below-discrimination but above-detection threshold stimuli can readily be categorized along semantic and affective dimensions.

Critically, there were no differences between subjects' categorization accuracies in the affective and semantic tasks, regardless of whether performance was indexed in terms of masking strength or as a function of subjective level of awareness. If affective processing was indeed prioritized in the auditory system, we would expect to see some indication of this bias reflected as an advantage for affective versus semantic categorization of stimuli that are not consciously perceived, or stimuli that the participant is only partially aware of. On the contrary, analyses of RTs indicated that semantic categorization was in fact faster than affective categorization. Again, this result is in line with evidence from the visual domain supporting semantic primacy (Lähteenmäki et al., 2015; Nummenmaa et al., 2010).

In conclusion, the results of Experiment 1 do not support the view that affective categorization does not require awareness or can be can be carried out in less time or with more limited resources than other types of auditory information categorization. Thus, in this respect, affective processing does not seem to constitute a "special" case of auditory information processing, even though the auditory system would have the necessary capacity for accessing affect prior to awareness.

Experiment 2

Experiment 1 suggests that affective and semantic categorization of auditory information does not take place in the absence of awareness. Nevertheless, it can be argued that the results were constrained to the specific stimuli or tasks used, and that nonconscious categorization or differences between affective and semantic tasks would have manifested if a different stimulus type or categorization task were used. To rule out this possibility, we conducted a second experiment in which we conceptually replicated Experiment 1. Rather than nonverbal vocalizations, we used three-digit numbers (e.g., "three hundred ninety-four") spoken with pleasant and unpleasant emotional prosody as target stimuli, and contrasted affective evaluations with two semantic categorization tasks: speaker gender judgments and decoding the semantic content of the speech.

As in Experiment 1, target stimuli were delivered at a random moment under continuous auditory suppression and three mask strengths were used. Participants performed, in separate blocks, 2AFC categorization of affective valence (pleasant vs. unpleasant), speaker gender (male vs. female), or lexical content (small vs. large number) of the target stimuli in three separate blocks. All stimuli could be categorized along all three task dimensions, and the same set of stimuli was used in all tasks. Participants performed PAS on all trials, and data were analyzed both as function of mask strength and subjective awareness ratings.

Method

Participants, stimuli procedure. Twenty-four university students (13 females and 11 males, age 19–30 years, $M_{age} = 22$ years) participated in the experiment. All participants had normal hearing and normal or corrected-to-normal vision and gave informed consent before participating. The stimuli were 24 vocalizations of English three-digit numbers spoken with pleasant or unpleasant emotional prosody (12 amusement, 12 sadness) by male (50%) and female (50%) speakers (Sauter, 2007). Half of the stimuli were numbers below 500, and the other half above 500. The stimuli lasted <2.5 s each. Additionally, 10 natural informational noise masks lasting 5 s each were constructed by mixing 20 randomly sampled tokens as in Experiment 1. All stimuli were normalized and sampled at 44100 Hz with 16-bit resolution. Stimuli were delivered via headphones and participants responded via key press. Attenuation levels were for strong, moderate and weak masking were determined according to same criteria as in Experiment 1 and set at weak: −0 dB, moderate: −10 dB, and strong: −18 dB. Stimulus presentation method and trial structure were otherwise identical to Experiment 1.

The experiment consisted of three blocks. In the *affective recognition block*, participants performed 2AFC categorization of affective category (amusement vs. sad), whereas in the *gender recognition block* they performed 2AFC recognition of speaker gender (male vs. female), and in the *number recognition block* they performed 2AFC categorization of lexical content of the tokens (small vs. large number, i.e., <500 vs. >500). Response latencies and accuracies were measured and the order of the blocks was counterbalanced across participants. Each block consisted of 180 trials presented in random order, and in each block all stimuli were presented twice at each masking level. As in Experiment 1, the 2AFC task was always followed by rating of stimulus awareness on the 4-point PAS-scale. In addition, each block contained 20% catch trials in which only the mask was presented. Participants were instructed to ignore the mask and focus on performing the categorization task as accurately as possible, and they were familiarized with the response protocol before the experiment and performed a practice session consisting of 20 trials before each stimulus block.

Results

The results are summarized in Figure 4. Data were again first analyzed as a function of masking strength. In all tasks, performance was at chance level under strong masking (.50 affective; .51 gender; .50 number), $ts(23) < .520$, $ps > .608$, $rs > .128$, and above chance level under moderate (.66 affective; .83 gender; 63. number) and weak (.92 affective; .98 gender; .90 number) masking, $ts(23) > 8.110$, $ps < .001$, $rs > .860$. The d' values for conscious detection of the stimuli under strong masking (.31 affective; −.21 gender; .20 number) did not differ from zero for any task, $ts(23) < 1.70$, $ps > .102$, $rs < .333$, indicating that the participants were not capable of conscious stimulus detection in any of the tasks when strong masking was applied.

Accuracy scores were subjected to a 3 (Task: affective vs. gender vs. number) × 3 (Masking Strength: weak vs. moderate vs. strong) ANOVA, which revealed main effects of masking strength, $F(2, 46) = 690.78$, $p < .001$, $\eta_p^2 = .968$, and task, $F(2, 46) = 28.19$, $p < .001$, $\eta_p^2 = .551$, as well as an interaction of Masking Strength × Task, $F(4, 92) = 13.84$, $p < .001$, $\eta_p^2 = .376$. To decompose the interaction, one-way ANOVAs of task (affective vs. gender vs. number) were conducted for each masking strength level, and revealed a significant effect of task under weak and moderate masking strength, $Fs(2,46) > 11.71$, $ps < .001$, $\eta_p^2s > .336$, but not under strong masking, $F(2, 46) = .075$, $p = .928$, $\eta_p^2 = .003$. Under weak and moderate masking, accuracy was significantly higher in the gender recognition task than in the affective or number recognition task, $ts(23) > 3.91$, $ps < .002$, $rs > .630$, while there were no differences between affective and number recognition tasks, $ts(23) < 1.35$, $ps > .192$, $r < .270$.

As in Experiment 1 we also analyzed the RT data despite long mean latencies (>3 s). The corresponding ANOVA on RTs yielded main effects of mask strength, $F(2, 46) = 31.07$, $p < .001$,

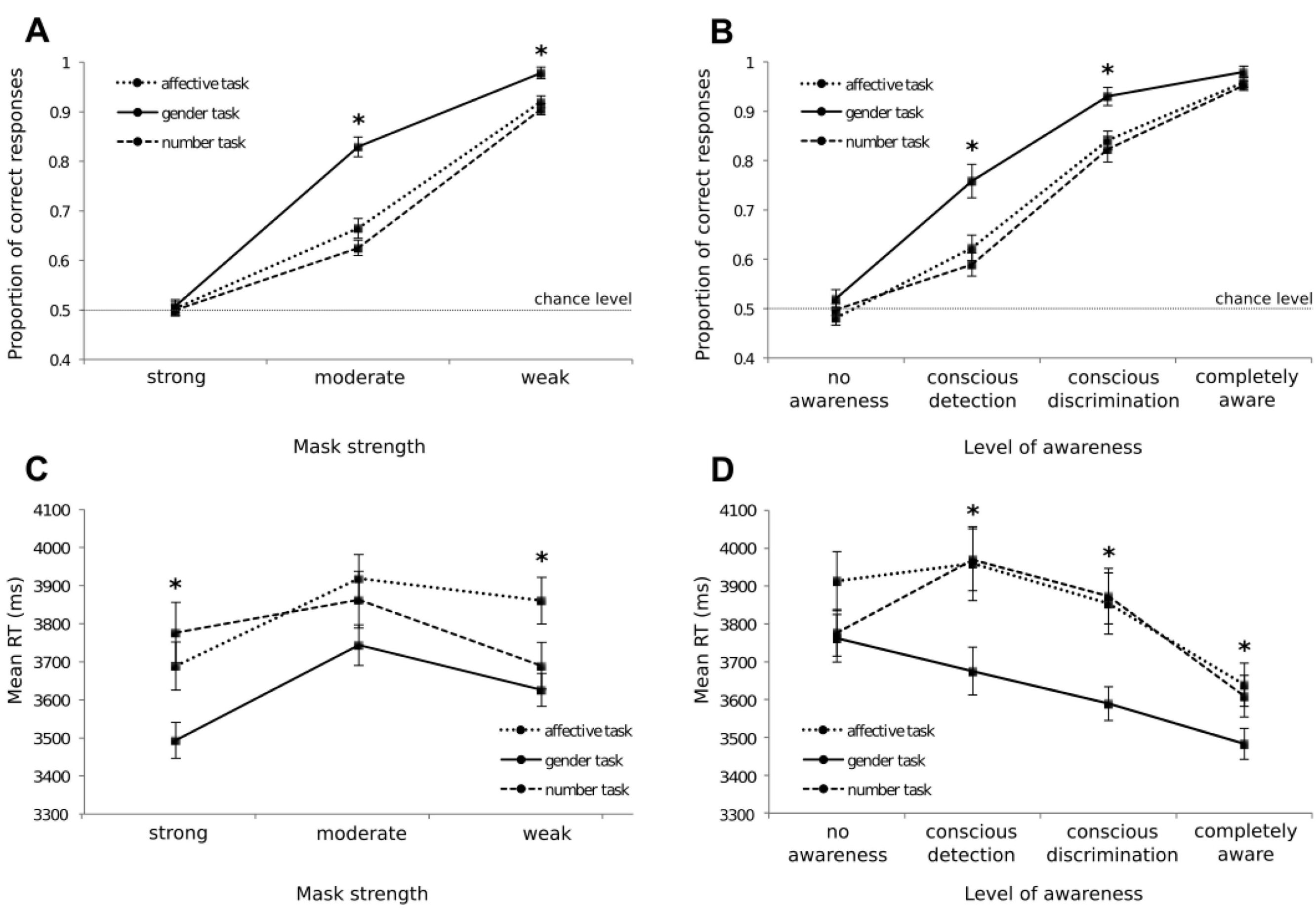

Figure 4. Means and standard errors for (A, B) response accuracies and (C, D) reaction times (RTs) in Experiment 2 as a function of mask strength and subjective level of awareness. Asterisk indicates significant differences between tasks following Bonferroni correction.

$\eta_p^2 = .575$, categorization task, $F(2, 46) = 10.91$, $p < .001$, $\eta_p^2 = .322$, and an interaction of Mask Strength × Categorization Task, $F(4, 92) = 7.20$, $p = .001$, $\eta_p^2 = .238$. Decomposing the interaction revealed a significant effect of categorization task at all levels of mask strength, $Fs(2,46) > 5.52$, $ps < .008$, $\eta_p^2s > .194$. At all levels of masking strength, gender categorization was faster than the affective or number recognition (weak: gender, 3,494 ms; affective, 3,689 ms; number 3,776 ms; moderate: gender, 3,744 ms, affective, 3,918 ms, number, 3,863 ms; strong: gender, 3,626 ms; affective, 3,860 ms, number, 3,698 ms). Paired comparisons with Bonferroni corrected alpha levels showed that this effect was significant for gender versus affective and gender versus number tasks under strong masking, $ts(23) > 3.78$, $ps < .002$, $rs > .618$, and for gender versus affective under weak masking, $t(23) = 3.85$, $p = .001$, $r = .626$. Differences in RTs between affective and number tasks were not significant at any mask strength, all $ts(23) < 2.45$, $ps > .022$, $rs < .455$, Bonferroni corrected.

Next, the data were analyzed as a function of the PAS ratings. One sample *t* tests demonstrated that, when participants reported having no awareness of the stimuli (awareness rating response 1), accuracies were at chance level in all tasks, $ts(23) < 1.23$, $ps > .228$, $rs < .249$. However, accuracy significantly differed from chance level when participants reported any awareness of the stimuli (awareness rating responses 2,3,4), $ts(23) > 3.78$, *ps [*lt] .001, $rs > .618$. A 3 (Categorization Task) × 4 (Level of Awareness) ANOVA was then conducted on accuracies. This revealed main effects of categorization task, $F(2, 46) = 20.13$, $p < .001$, $\eta_p^2 = .467$, and level of awareness, $F(3, 69) = 271.61$, $p < .001$, $\eta_p^2 = .922$, and an interaction of Categorization Task × Level of Awareness, $F(6, 138) = 3.93$, $p = .005$, $\eta_p^2 = .146$. Decomposing the interaction through separate one-way ANOVAs for each level of awareness revealed a significant effect of categorization task for all partially aware stimuli (PAS ratings 2, 3), $Fs(2,46) > 7.19$, $ps < .005$, $\eta_p^2s > .237$, whereas no differences were observed in complete absence of awareness, nor for completely aware stimuli (PAS ratings 1, 4), $Fs(2,46) = 2.17$, $ps > .132$, $\eta_p^2s < .086$. For all partially aware stimuli, accuracy was higher in the gender recognition task than in the affective or number recognition task, $ts(23) > 3.00$, $ps < .007$, $rs > .530$, whereas no differences between affective and number task were observed under any level of awareness, $ts(23) < .984$, $ps > .334$, $rs > .201$. In all tasks, performance improved with each increase in reported level of awareness (no awareness: .48 affective, .52 gender, .50 number; consciously detected: .62 affective, .75 gender, .59 number; consciously discriminated: .84 affective, .93 gender, .82 number; completely aware: .96 affective, .98 gender, .95 number). Simple linear regression analysis was then conducted to predict accuracy based on level of awareness, and showed that level of awareness significantly predicted accuracy for all categorization tasks, $\beta s > .16$, $ts(94) > 12.97$, $ps < .001$, and explained a significant proportion of variance in all tasks, $R^2s > .716$, $Fs(1, 94) > 238.45$, $ps < .001$.

For RTs, the corresponding 3 (Categorization Task) × 4 (Level of Awareness) ANOVA yielded main effects of categorization task, $F(2, 46) = 11.89$, $p < .001$, $\eta_p^2 = .341$, and level of awareness, $F(3, 69) = 24.19$, $p < .001$, $\eta_p^2 = .513$, and an interaction of categorization Task × Level of Awareness, $F(6, 138) = 4.22$, $p = .004$, $\eta_p^2 = .155$. Decomposing the interaction yielded a significant effect of categorization task at all levels of awareness, $Fs(2,46) > 4.08$, $ps > .032$, $\eta_p^2s > .151$. Paired comparisons tests following Bonferroni correction showed that for all aware stimuli, RTs were significantly faster in the gender task versus the affective or number task, $ts(23) > 3.10$, $ps < .006$, $rs > .543$, whereas there were no significant differences between affective and number tasks at any mask strength, nor between any tasks in the complete absence of awareness (no awareness: affective, 3,913 ms, gender, 3,761 ms, number, 3,776 ms; consciously detected: affective, 3,960 ms, gender, 3,675 ms, number, 3,969 ms; consciously discriminated: affective, 3,854 ms, gender, 3,589 ms, number, 3,873 ms; completely aware: affective, 3,640 ms, gender, 3,483 ms, number, 3,609 ms), all $ts(23) < 2.39$, $ps > .026$, $rs < .446$, Bonferroni corrected.

Discussion

Experiment 2 confirms that semantic and affective auditory categorization is contingent on awareness across multiple task domains. Under strong masking categorization, (a) performance in all tasks was consistently at chance level, (b) no differences in accuracy between tasks were observed, and (c) d' scores verified that the participants could not consciously detect the primes. Analysis as function of awareness confirmed that when participants reported no conscious perception of the stimuli, accuracy was at chance level in all tasks. At all levels of awareness where stimuli were consciously perceived (ratings 2, 3, and 4) all three tasks could be performed above chance level, and in all tasks accuracies increased linearly as a function of awareness. All in all, these results show that both affective and semantic categorization is dependent on awareness.

Notably, for all masking strengths where categorization could be successfully performed, accuracy in the gender task was significantly higher than in the affective or number tasks. Further, analyses as a function of awareness rating showed that accuracy was greater for the gender task versus affective or number task only when stimuli were only partially perceived (awareness ratings 2 and 3). In general, this shows that extracting different types of category information posed different demands for consciousness. However, semantic (gender) rather than affective information required the least auditory information for successful categorization, providing evidence against the affective primacy hypothesis. Importantly, for completely aware trials there were no differences in accuracies between tasks, confirming that the differences observed under partial awareness do not stem from differential levels of base difficulty between the tasks.

Finally, RTs demonstrate that gender categorization was systematically faster than affective or number categorization. As this difference manifests itself at all mask strengths and is significant for weak masking with clearly audible stimuli as well as strong masking where the stimuli were not consciously perceived, the results indicate that this finding represents a general difference in processing time allocated to the different cognitive tasks regardless of whether stimuli can successfully categorized or consciously perceived. Nevertheless, analysis of awareness rating responses indicates that the difference is amplified when participants are aware of the stimuli. These results accord with findings from the visual domain indicating that an initial semantic categorization precedes affective evaluation (Nummenmaa et al., 2010). Moreover, as RTs in the number task involving semantic recognition of the lexical information did not differ from affective task RTs, the results of Experiment 2 also demonstrate that semantic processing is not *universally* faster than affective processing; instead complex semantic categorization operations can be on par or may take longer to accomplish (Lähteenmäki et al., 2015) than affective evaluations. Together, these findings strongly support the notion that semantic categorization is faster than affective evaluation (Lähteenmäki et al., 2015; Nummenmaa et al., 2010; Storbeck, Robinson, & McCourt, 2006), and argue against the affective primacy hypothesis (Zajonc, 1980).

Experiment 3

Experiments 1 and 2 established that explicit affective and semantic auditory categorization require awareness. Yet, it is possible that affective or semantic stimulus processing could have been carried out to some extent in the absence of awareness, but that this processing was insufficient to influence performance in a conscious decision-making task, and that the resultant affective or semantic responses were too weak to elicit a conscious percept. In Experiment 3 we tested this possibility with a masked auditory priming paradigm, which enables quantification of implicit affective and semantic processing. To ensure that all possible affective and semantic information in the probe were available immediately upon prime onset and remained accessible throughout stimulus presentation, we used visual probes, specifically emotional facial expressions. Moreover, using different sensory modalities for the prime and probe ensured that the associations between prime and probe were purely conceptual (i.e., affective or semantic), thus preventing any occurrence of perceptual priming effects that could otherwise confound the data.

The effectiveness of the cross-modal paradigm has been established for both affective (Carroll & Young, 2005; Gohier et al., 2013) and semantic priming (Chen & Spence, 2013; Scherer & Larsen, 2011; Tabossi, 1996; Young, Hellawell, & De Haan, 1988) using both auditory-visual and visual-auditory prime-probe combinations, and with stimulus categories ranging from words (Davis & Kim, 2015; Holcomb & Anderson, 1993; Scherer & Larsen, 2011), numbers (Kouider & Dehaene, 2009) and faces (Young et al., 1988) to environmental sounds (Kim, Porter, & Goolkasian, 2014). These data imply that cross-modal priming is a robust effect and thus a suitable proxy for this first-ever investigation of cross-modal priming effects with nonconscious auditory primes.

The participants performed affective and semantic categorization of probes that were preceded by masked primes. Prime audibility was again manipulated by attenuating prime volume, while the mask volume was fixed. The primes were the pleasant and unpleasant emotional vocalizations from Experiment 1, and the probes were fearful and happy facial expressions from the Karolinska Directed Emotional Faces database (Lundqvist, Flykt, & Öhman, 1998). Both the primes and the probes could be categorized according to either their affective valence (pleasant vs. unpleasant) or semantic category (male vs. female), and were combined so that the prime-probe pair could be congruent on both dimensions (e.g., female amusement sound followed by happy female face), incongruent in both (e.g., female amusement sound followed by fearful male face), or congruent in one and incongruent in the other (e.g., female amusement sound followed by fearful female; female amusement sound followed by happy male face), resulting in 16 different prime-probe congruency combinations (see Figure 5). RTs and accuracies were again measured. To index the participants' awareness of the primes, the participants rated their conscious percept of the prime on the PAS-scale on each trial after the categorization task.

Even though affective auditory-visual cross-modal priming has been demonstrated previously (Carroll & Young, 2005) we conducted a pilot experiment to validate our cross-priming design. The pilot experiment consisted of an affective and a semantic block with clearly audible unmasked primes presented at interstimulus intervals (ISIs) of 0, 300, and 600 ms. Affective priming ($ps < 0.05$) for fear and amusement was observed at all three ISIs, whereas triumph and disgust elicited priming effects only at ISI of 300 ms. Consequently, stimulus onset asynchrony (SOA) of 300 ms was chosen to maximize the likelihood of observing unconscious affective priming if such a phenomenon exists. Finally, to account for the possibility that nonconscious auditory affective or semantic processing might manifest in a within—but not between—modality priming design, we also conducted a purely auditory priming experiment ($n = 20$) using the nonverbal emotional vocalizations as primes and probes to test for the possibility of implicit within-modality affective or semantic nonconscious auditory processing; Trial structure and design were otherwise identical with the cross-priming experiment. In this within-

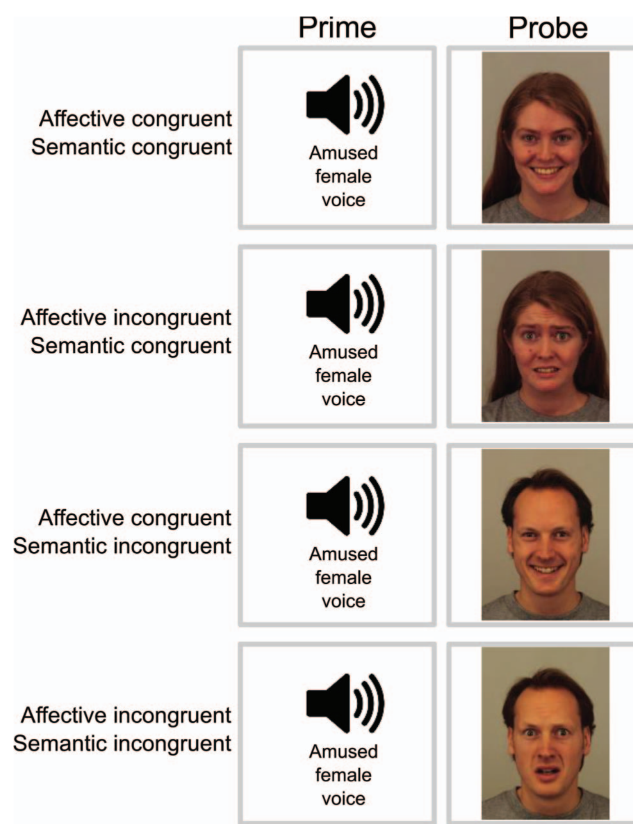

Figure 5. Examples of prime-probe congruency combinations for one prime category (amused female). With happy and fearful female and male probe faces. Images AF22HAS, AF22AFS, AF10HAS, AF10AFS from the Karolinska Directed Emotional Faces (KDEF) database. See the online article for the color version of this figure.

modality priming experiment neither semantic nor affective priming were observed for conscious or nonconscious primes.

Method

Participants. Forty-eight university students (22 females and 26 males, age 19–35 years, M_{age} = 24 years) participated in the experiment. All participants had normal hearing and normal or corrected-to-normal vision.

Stimuli and apparatus. The auditory prime stimuli were 20 nonverbal vocalizations of positive and negative emotions (10 amusement, 10 fear; five male and five female tokens in each category) and the natural noise masks from Experiment 1. The primes were cropped to 700 ms to minimize temporal variability between stimuli; this was done in such a way that no artificial onsets/offsets were produced. Recognizability of the cropped stimuli was verified by two independent observers, who correctly recognized all individual tokens along both affective and semantic dimensions. In addition, 80 pictures of emotional facial expressions (20 happy females, 20 happy males, 20 fearful females, 20 fearful males) were selected from the Karolinska Directed Emotional Faces database and used as probes in the experiment. This stimulus set has previously been used in a masked priming study (Lähteenmäki et al., 2015) and shown to elicit both affective and semantic priming.

Procedure. The experiment consisted of two experimental conditions (affective and semantic) with identical trial structure and stimuli (see Figure 6). Each trial began with a fixation cross displayed at the center of the screen for 1 s, followed by a randomly selected noise mask that lasted 1.7 s. As masked priming effects are dependent on temporal allocation of attention on the prime-probe time window (Naccache, Blandin, & Dehaene, 2002), the prime was always presented after a fixed 1-s delay from mask onset for a duration of 700 ms. Then, following a 300 ms delay from prime offset, the probe was presented for 200 ms, and was followed by a question mark which signaled to the subject to give their response. The categorization task always preceded the prime awareness rating on the 4-point PAS-scale; in the latter task there was no time-pressure. The next trial began after the participant gave their response on the awareness rating task.

Prime audibility was attenuated in three steps (weak, moderate, strong) as in Experiment 1. Each prime was presented 24 times (eight times at each masking level) and each probe was presented six times (twice at each masking level) in each condition. Each condition consisted of 580 trials, out of which 100 were catch trials in which no prime was presented. Participants were randomly assigned to either the affective or the semantic condition; 24 participants took part in each. In the affective condition, participants performed affective evaluations (fearful vs. happy) of the probes, and in the semantic condition the probes were categorized semantically (male vs. female). This resulted in a mixed 3 (Mask Strength: weak vs. moderate vs. strong) × 2 (Congruency: congruent vs. incongruent) × 2 (Task: semantic vs. affective) design with mask strength and congruency as within subjects factor and task as a between-subjects factor.

The participants were told that each trial consists of the mask and prime sounds, followed by the target picture. They were instructed to ignore the prime and focus on categorizing the target as accurately and quickly as possible. Before the experiment the participants were familiarized with the response protocol and performed a short practice session consisting of 20 trials. RTs and accuracies were measured.

Results

The results are summarized in Figure 7. Data were again first analyzed as a function of masking strength. Accuracy and RT scores were subjected to 2 (Task: semantic vs. affective) × 2 (Congruency: congruent vs. incongruent) × 3 (Mask Strength: weak vs. moderate vs. strong) ANOVAs with Task as a between-subjects factor. For accuracies, the ANOVA yielded a main effect of congruency, $F(1, 46) = 8.16$, $p = .006$, $\eta_p^2 = .151$, which was qualified by an interaction of Mask Strength × Congruency, $F(2, 92) = 5.13$, $p = .008$, $\eta_p^2 = .100$. There were no other significant main effects or interactions, all Fs < 2.53. Paired sample t tests for congruent versus incongruent trials at each level of Mask strength revealed that affective and semantic accuracies were higher for congruent versus incongruent trials for primes under weak (.94 congruent; .92 incongruent) masking, $t(47) = 3.89$, $p < .001$, $r = .493$, but not under moderate (.94 congruent; .93 incongruent) or strong (.94 congruent; .93 incongruent) masking, ts(47) < .86, ps > .396, rs < .125.

The corresponding ANOVA on RTs revealed main effects of Mask Strength, $F(2, 92) = 20.81$, $p < .001$, $\eta_p^2 = .312$, and

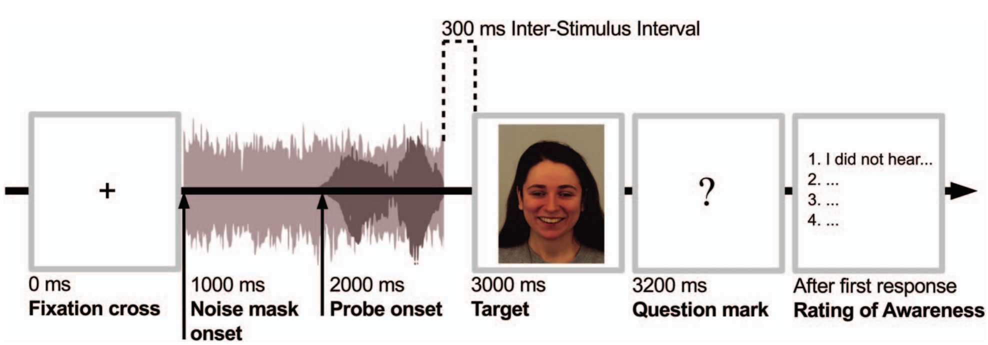

Figure 6. Trial structure in Experiment 2. Event times indicate the onset of each event relative to the beginning of the trial. Image AF15HAS from the Karolinska Directed Emotional Faces (KDEF) database. See the online article for the color version of this figure.

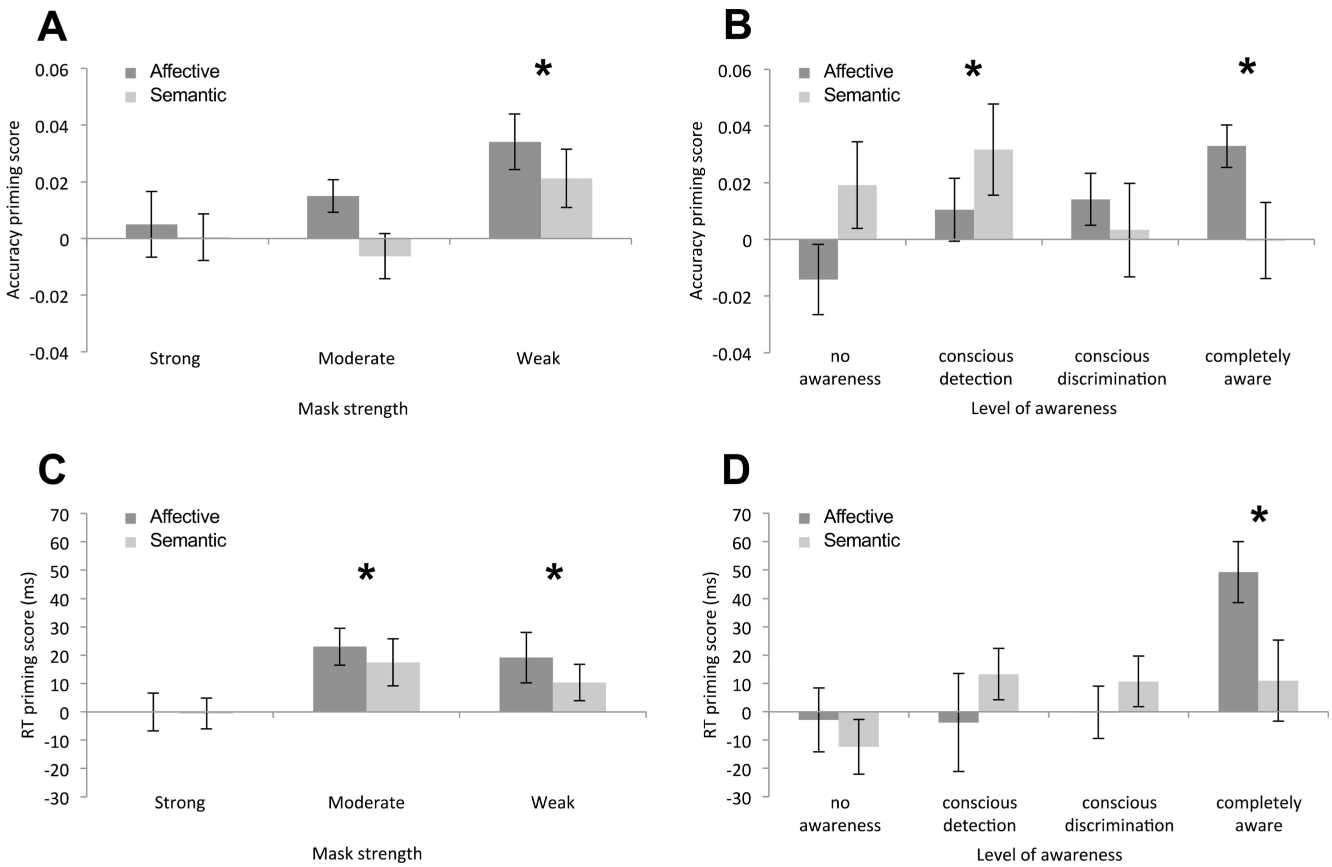

Figure 7. Means and standard errors of mean of priming scores (incongruent-congruent) for reaction time (RT) in Experiment 3. (A) Accuracy priming scores for affective and semantic categorization as a function of mask strength. (B) RT priming scores for affective and semantic categorization as a function of mask strength. (C) Accuracy priming scores as a function of awareness. (D) RT priming scores as a function of awareness. Asterisk indicates significant main effect of congruency.

congruency, $F(1, 46) = 12.29$, $p = .001$, $\eta_p^2 = .211$, and an interaction of Mask Strength × Congruency, $F(2, 92) = 5.15$, $p = .008$, $\eta_p^2 = .101$. RTs were significantly faster for congruent versus incongruent primes under weak (mean priming score 15 ms) and moderate (mean priming score 20 ms) masking, $ts(47) > 2.69$, $ps < .011$, $rs > .364$ but not under strong (mean priming score <1 ms) masking, $t(47) = .075$, $p = .940$, $r = .010$. There were no other significant effects, $Fs < 2.3$.

The d's for primes under strong masking (1.33 affective; .47 semantic) significantly differed from zero in both tasks, $ts(23) > 4.23$, $ps < .001$, $rs > .627$, indicating that the participants could consciously detect the primes on some trials even when strong masking was applied. Accuracy and RT scores were next analyzed as a function of the awareness rating responses. The 2 (Task) × 2 (Congruency) × 4 (Level of Awareness) ANOVA on accuracies produced a main effect of congruency, $F(1, 46) = 4.85$, $p = .033$, $\eta_p^2 = .095$, which was modified by a three-way interaction of Congruency × Level of Awareness × Task, $F(3, 138) = 3.14$, $p = .027$, $\eta_p^2 = .064$. Decomposing the interaction by separate 2 (Task) × 2 (Congruency) ANOVAs at each level of awareness revealed a main effect of Congruency for consciously detected primes and completely aware primes, $Fs(1, 46) > 4.45$, $ps < .041$, $\eta_p^2s > .087$, which were modified by an interaction of Congruency × Task, $F(1, 46) = 4.67$, $p = .036$, $\eta_p^2 = .093$. There were no other main effects or interactions, $Fs < 2.2$. There were no differences between incongruent versus congruent trials in either task in the complete absence of awareness, $ts(23) < 1.55$, $ps > .136$, $rs > .627$, whereas higher accuracies for congruent versus incongruent trials were observed for consciously detected primes in the semantic task (awareness rating 2: .96 congruent vs. .93 incongruent) and for completely aware primes in the affective task (awareness rating 4: .94 congruent vs. .91 incongruent), however, these effects did not survive Bonferroni corrections for multiple comparisons, $ts(23) < 2.45$, $ps > .022$, $rs < .455$.

The corresponding ANOVA on RTs revealed main effects of Level of Awareness, $F(3, 138) = 7.83$, $p < .001$, $\eta_p^2 = .145$, and congruency, $F(1, 46) = 4.58$, $p = .038$, $\eta_p^2 = .091$. An interaction of Level of Awareness × Congruency, $F(2.6, 118.0) = 3.51$, $p = .023$, $\eta_p^2 = .071$, revealed that affective and semantic RTs were on average 30 ms, 95% confidence interval [12.1, 48.1], faster for congruent versus incongruent trials when the participants were completely aware of the primes, $t(47) = 3.24$, $p = .002$, $r = .427$, while there were no differences between congruent and incongruent trials for partially aware primes or in the complete absence of awareness, *t*s(47) < 1.04, *p*s $> .306$, *r*s $< .151$. Main effect of Task or interactions involving Task were not significant, *F*s < 2.66.

Discussion

Experiment 3 shows that implicit affective and semantic processing of auditory information are similarly dependent on awareness. Affective and semantic cross-modality priming was observed for accuracies and RTs, and analysis of the awareness rating responses confirmed that priming effects were only elicited when the participants were aware of the primes. The general cross-modal priming effect accords well with prior studies (Carroll & Young, 2005), and also extends them in showing that even though auditory-visual cross-priming occurs with masked primes, priming effects nevertheless only emerge when the masked stimuli give rise to conscious perception of the prime. Moreover, as the primes and probes were of different physical stimulus modalities, the results suggest that the observed affective and semantic priming effects reflect sensory domain-independent activation of emotional and semantic evaluation systems, rather than perceptual priming effects elicited by purely sensory stimulus features (e.g., perceptual affective priming effects in Calvo, Fernández-Martín, & Nummenmaa, 2012). Finally, our results complement previous studies on cross-modality face priming (Bulthoff & Newell, 2017; Stevenage, Hale, Morgan, & Neil, 2014) in showing that face processing can be modulated by both affective and semantic vocal features.

Notably, d' scores indicate that in Experiment 3 participants were more sensitive to consciously detecting the stimuli than in Experiment 1. Critically, in Experiment 1 the stimulus was presented at a random moment within the continuous noise mask, whereas in Experiment 3 the presentation time was fixed to optimize priming effects. Thus, in Experiment 3 participants were able to focus temporal attention on the prime to increase the likelihood of a conscious percept while in the first experiment they could not. This supports the notion that attentional focusing increases accessibility of low-threshold stimuli for awareness (Koivisto et al., 2008). However, in Experiment 3 the d' scores were noticeably higher in the affective than the semantic task. This difference between the tasks suggests that temporal attention has a differential effect on affective and semantic recognition, in that successful allocation of temporal attention may enhance access of affective information into awareness. Nevertheless, it is important to note that despite such residual prime awareness the priming scores remained consistently at zero.

General Discussion

Our main findings were that (a) implicit and explicit auditory affective and semantic categorization require awareness and that (b) auditory semantic categorization is faster than auditory affective recognition. In the absence of awareness, explicit affective and semantic categorization accuracies in both categorization experiments were at chance level and priming scores did not differ from zero. When stimuli were consciously perceived, explicit affective and semantic categorization could be accomplished above chance level and both affective and semantic priming were observed. Analysis of categorization speed further revealed that semantic categorization was faster, and under limited awareness more accurate than affective evaluation. Together, these results argue against the notion that affective processing can be performed outside of awareness (LeDoux, 1998; Tamietto & De Gelder, 2010) or faster than semantic processing (Murphy & Zajonc, 1993; Zajonc, 1980), and corroborate a position of semantic primacy (Nummenmaa et al., 2010).

Auditory Affective Categorization Requires Awareness

The primary contribution of the present study is in showing that affective and semantic auditory categorization are similarly contingent on awareness. Both explicit (PAS) and implicit (priming scores) measures were convergent and showed that neither affective nor semantic processing took place when the participants had no conscious perception of the stimulus. In the explicit tasks, performance in both affective and semantic recognition increased linearly (affective $R^2 = .609$, semantic $R^2 = .396$) with increasing awareness, yet critically, there were no differences between affective and semantic categorization accuracies or RTs at any level of awareness (or masking).

In line with these above findings, results from the implicit tasks showed that while both affective and semantic priming effects were observed when participants were aware of the masked primes, neither affective nor semantic priming was elicited by primes that were not consciously perceived. It must be emphasized that even though the human auditory system would have the anatomical capacity to perform affective evaluations in the absence of awareness (Keifer et al., 2015), the present experiments demonstrates that affective auditory categorization can only be carried out when the stimuli are consciously perceived. Importantly, within the visual domain, affective recognition has been shown to be similarly contingent on awareness (Hedger et al., 2015; Lähteenmäki et al., 2015; Pessoa, 2005; Pessoa et al., 2006). Thus, the combined evidence suggests that in both sensory systems, the processing of emotional information involves higher order cortical processing.

The present study however does show that both affective and semantic auditory categorization can be carried out with limited stimulus information, and even for stimuli below the conscious discrimination threshold (Experiment 1). As similar observations have been made for affective and semantic visual categorization operations (Lähteenmäki et al., 2015), the capability for categorizing stimuli that cannot be consciously discriminated is likely a general feature of sensory processing. It must nevertheless be stressed that, in both the auditory and visual experiments, semantic categorization performance of these marginally conscious stimuli was always of equal or higher accuracy than affective categorization performance. Consequently, categorization of stimuli that are marginally consciously perceived is by no means specific to affect, and thus cannot be taken to support the affective primacy hypothesis (Zajonc, 1980, 2000).

Moreover, the awareness rating distributions (see Table 1) indicate that even when strong masking was applied, the low-intensity stimuli could still be consciously detected on a substantial number of trials. Because detection sensitivity varies substantially between participants (Pessoa et al., 2005) and across trials due to attentional fluctuations and changes in level of arousal (Macmillan & Creelman, 2004), we stress that the dependence of affective and

Table 1
Distribution of Awareness Rating Responses for Each Mask Strength in Each Experiment

Experiment	Mask strength	No awareness	Proportion of awareness rating responses		
			Something (guess)	Partially aware	Completely aware
1	Weak	.04	.16	.31	.49
	Moderate	.33	.33	.22	.12
	Strong	.69	.22	.07	.02
2	Weak	.01	.04	.22	.73
	Moderate	.28	.37	.29	.06
	Strong	.81	.16	.03	.01
3	Weak	.04	.08	.25	.63
	Moderate	.09	.17	.31	.43
	Strong	.31	.25	.21	.23

semantic processing on awareness can only be detected when trial-wise analysis of subjective level of perception is applied. Even if purely no-aware trials result in a mean zero performance, and trials where stimuli reach awareness in positive nonzero performance, any experimental design allowing leakage of stimuli into awareness even on a subset of trials will ultimately manifest "unaware" stimulus processing due to averaging.

Because trial-wise measures of awareness have not been employed in most studies on nonconscious perception (e.g., Liddell, Williams, Rathjen, Shevrin, & Gordon, 2004; Nomura et al., 2004; Phillips et al., 2004; Williams et al., 2004, 2006, and others), it is likely that previous studies on nonconscious affective perception may have largely documented effects that have in fact taken place under marginal stimulus awareness. Yet, when trialwise control of awareness is conducted, results from both auditory and visual domains show that affective and cognitive categorization operations do not take place in the absence of awareness (see, e.g., Hedger et al., 2015; Lähteenmäki et al., 2015; Pessoa et al., 2006; Pessoa et al., 2005). Even more importantly, quantitative meta-analytic evidence suggests that effect sizes for nonconscious affective processing are largest in the studies involving less rigorous means for controlling awareness (Lähteenmäki et al., 2015). Altogether these findings question the widely accepted account that stimuli not reaching even partial awareness could significantly modulate cognitive processing of perceptual information (Bornstein & Pittman, 1992; Dixon, 1971). However, it is still possible that some forms of overlearned affective responses (such as fast activation of fear in phobics) or perception-action links can be triggered by stimuli that are not consciously perceived (Lamme, 2006; Larson et al., 2006), yet this line of research requires significantly more work to establish the boundary conditions leading to affective responses under minimal awareness.

Auditory Semantic Processing Is Faster Than Affective Processing

The second main finding of the present study is in showing that in the auditory system, semantic categorization can be performed more quickly and with lower demand on awareness than affective evaluations. Analogously with findings from the visual domain (Lähteenmäki et al., 2015; Nummenmaa et al., 2010; Storbeck et al., 2006), mean response latencies in both categorization experiments revealed that RTs were systematically faster for semantic gender categorization than for affective evaluation of valence. Results of Experiment 2 further complemented this picture by showing that while increased semantic over affective RTs are present at all levels of awareness, the difference is amplified when the stimuli are consciously perceived. Interestingly, these results seem to contrast findings from the visual domain in the sense that in Experiment 2 a weak difference between affective and semantic speeds was present when stimuli were not consciously perceived, despite chance-level categorization performance for these stimuli, whereas in the visual modality differences between categorization operations only manifested when categorization could be performed above chance level. Given that in the present study accuracies nevertheless did not differ from chance level, the result suggests that the differential latencies reflect in part a difference in decision-making speed in the semantic versus affective tasks and not merely affective and semantic processing speeds of auditory stimuli. Yet, as differences between semantic and affective categorization RTs are substantially increased for all stimuli that are consciously perceived, the combined results suggest that in addition to differential base decision-making time, processing of the relevant features for affective and semantic categorization of the same stimuli also take longer for affective versus semantic cues to accomplish.

Importantly, with respect to the reliability of the RTs for indexing categorization speed, it must be considered that in the present experiments the participants always gave their response after the entire masker presentation had ended, and that mask offset time was always equal to or greater than target offset. Consequently, the obtained RTs also reflect the extra time taken for listening to the entire auditory presentation and making a consequent forced-choice affective or semantic decision. Thus, the RTs cannot be taken as measures of absolute affective or semantic response speeds. Nevertheless, as presentation durations were identical and same stimuli were used across affective and semantic tasks, the RTs provide information on relative differences in affective versus semantic categorization speeds. Thus, as RT in the number task involving lexical content of the auditory stimuli did not differ from affective RTs, the results indicate that semantic primacy in the auditory is not universal, and instead more complex semantic tasks can be on par or take longer to accomplish than affective evaluation.

Directly opposed to what is predicted by the affective primacy hypothesis (Murphy & Zajonc, 1993; Zajonc, 1980), categorization accuracies revealed that when stimulus signal-to-noise ratio was manipulated such that the stimuli were only partially consciously perceived, semantic categorization of gender could be performed at a higher accuracy than affective categorization, indicating that auditory semantic features can be decoded from a weaker signal than affective features of the same stimuli and that within the auditory system semantic processing has a lower demand on consciousness than affective processing. Again, this result is in line with findings from the visual modality showing that semantic categorization requires less sensory information than affective evaluation (Nummenmaa et al., 2010).

Finally, it must be noted that our findings are limited by the fact that we only used behavioral measures to index affective and semantic processing, thus restricting the extent to which generalization to all affective and semantic processing can be made on the basis of the present results. It can be argued that some degree of affective or semantic processing may have occurred in the absence of awareness, and that indices of such processing could have been obtained using physiological measures such as facial electromyography, galvanic skin responses or brain imaging. However, the present results demonstrate that even if such processing exists, it is insufficient to modulate behavior.

Conclusions

We conclude that affective and semantic categorization are similarly dependent on awareness, yet auditory semantic processing is faster than auditory affective processing. Both implicit and explicit measures of affective categorization show that affective and semantic processing only occur when there is sufficient stimulus information for awareness to emerge. When participants are even marginally aware of the stimuli, affective and semantic categorization can be carried out with equal accuracy, however, this capability for processing stimuli that cannot be consciously discriminated is a general property of sensory information processing and is not specific to affect. Last, the present study shows that under limited awareness semantic categorization is more accurate than affective recognition. Taken together, our results support the view that all auditory semantic and affective processing are dependent on awareness, and indicate semantic over affective primacy.

References

Adolphs, R., Russell, J. A., & Tranel, D. (1999). A role for the human amygdala in recognizing emotional arousal from unpleasant stimuli. *Psychological Science, 10,* 167–171. http://dx.doi.org/10.1111/1467-9280.00126

Adolphs, R., Tranel, D., Damasio, H., & Damasio, A. (1994). Impaired recognition of emotion in facial expressions following bilateral damage to the human amygdala. *Nature, 372,* 669–672. http://dx.doi.org/10.1038/372669a0

Bargh, J. A. (1997). The automaticity of everyday life. In R. S. Wyer, Jr., (Ed.), *The automaticity of everyday life: Advances in social cognition* (Vol. 10, pp. 1–61). Mahwah, NJ: Erlbaum.

Bordi, F., & LeDoux, J. E. (1994). Response properties of single units in areas of rat auditory thalamus that project to the amygdala. I. Acoustic discharge patterns and frequency receptive fields. *Experimental Brain Research, 98,* 261–274. http://dx.doi.org/10.1007/BF00228414

Bornstein, R. F., & Pittman, T. S. (1992). *Perception without awareness: Cognitive, clinical, and social perspectives*. New York, NY: Guilford Press.

Bülthoff, I., & Newell, F. N. (2017). Crossmodal priming of unfamiliar faces supports early interactions between voices and faces in person perception. *Visual Cognition*. Advance online publication. http://dx.doi.org/10.1080/13506285.2017.1290729

Calvo, M. G., Fernández-Martín, A., & Nummenmaa, L. (2012). Perceptual, categorical, and affective processing of ambiguous smiling facial expressions. *Cognition, 125,* 373–393. http://dx.doi.org/10.1016/j.cognition.2012.07.021

Calvo, M. G., & Nummenmaa, L. (2007). Processing of unattended emotional visual scenes. *Journal of Experimental Psychology, 136,* 347–369. http://dx.doi.org/10.1037/0096-3445.136.3.347

Campeau, S., & Davis, M. (1995). Involvement of subcortical and cortical afferents to the lateral nucleus of the amygdala in fear conditioning measured with fear-potentiated startle in rats trained concurrently with auditory and visual conditioned stimuli. *The Journal of Neuroscience, 15,* 2312–2327.

Carroll, N. C., & Young, A. W. (2005). Priming of emotion recognition. *The Quarterly Journal of Experimental Psychology Section A, 58,* 1173–1197. http://dx.doi.org/10.1080/02724980443000539

Cauchoix, M., & Crouzet, S. M. (2013). How plausible is a subcortical account of rapid visual recognition? *Frontiers in Human Neuroscience, 7,* 39. http://dx.doi.org/10.3389/fnhum.2013.00039

Chen, Y.-C., & Spence, C. (2013). The time-course of the cross-modal semantic modulation of visual picture processing by naturalistic sounds and spoken words. *Multisensory Research, 26,* 371–386.

Davis, C., & Kim, J. (2015). Masked cross-modal priming turns on a glimpse of the prime. *Consciousness and Cognition, 33,* 457–471. http://dx.doi.org/10.1016/j.concog.2015.02.016

Dixon, N. F. (1971). *Subliminal perception: The nature of a controversy*. New York, NY: McGraw-Hill.

Doron, N. N., & Ledoux, J. E. (1999). Organization of projections to the lateral amygdala from auditory and visual areas of the thalamus in the rat. *The Journal of Comparative Neurology, 412,* 383–409. http://dx.doi.org/10.1002/(SICI)1096-9861(19990927)412:3<383::AID-CNE2>3.0.CO;2-5

El Ayadi, M., Kamel, M. S., & Karray, F. (2011). Survey on speech emotion recognition: Features, classification schemes, and databases. *Pattern Recognition, 44,* 572–587. http://dx.doi.org/10.1016/j.patcog.2010.09.020

Gohier, B., Senior, C., Brittain, P. J., Lounes, N., El-Hage, W., Law, V., . . . Surguladze, S. A. (2013). Gender differences in the sensitivity to negative stimuli: Cross-modal affective priming study. *European Psychiatry, 28,* 74–80. http://dx.doi.org/10.1016/j.eurpsy.2011.06.007

Gosselin, N., Peretz, I., Johnsen, E., & Adolphs, R. (2007). Amygdala damage impairs emotion recognition from music. *Neuropsychologia, 45,* 236–244. http://dx.doi.org/10.1016/j.neuropsychologia.2006.07.012

Grill-Spector, K., & Kanwisher, N. (2005). Visual recognition: As soon as you know it is there, you know what it is. *Psychological Science, 16,* 152–160. http://dx.doi.org/10.1111/j.0956-7976.2005.00796.x

Hain, C. H., & Micco, A. (2003). Cranial nerve VIII: Vestibulocochlear system. In C. G. Goetz (Ed.), *Textbook of clinical neurology* (2nd ed., pp. 195–210). Philadelphia, PA: Elsevier Science.

Hedger, N., Adams, W. J., & Garner, M. (2015). Autonomic arousal and attentional orienting to visual threat are predicted by awareness. *Journal of Experimental Psychology: Human Perception and Performance, 41,* 798–806. http://dx.doi.org/10.1037/xhp0000051

Hermans, D., Spruyt, A., De Houwer, J., & Eelen, P. (2003). Affective priming with subliminally presented pictures. *Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Expérimentale, 57,* 97–114. http://doi.org/10.1037/h0087416

Holcomb, P. J., & Anderson, J. E. (1993). Cross-modal semantic priming: A time-course analysis using event-related brain potentials. *Language and Cognitive Processes, 8,* 379–411. http://dx.doi.org/10.1080/01690969308407583

Imura, K., & Rockland, K. S. (2006). Long-range interneurons within the medial pulvinar nucleus of macaque monkeys. *The Journal of Comparative Neurology, 498,* 649–666. http://dx.doi.org/10.1002/cne.21085

Keifer, O. P., Jr., Gutman, D. A., Hecht, E. E., Keilholz, S. D., & Ressler, K. J. (2015). A comparative analysis of mouse and human medial geniculate nucleus connectivity: A DTI and anterograde tracing study. *NeuroImage, 105,* 53–66. http://dx.doi.org/10.1016/j.neuroimage.2014.10.047

Kim, Y., Porter, A. M., & Goolkasian, P. (2014). Conceptual priming with pictures and environmental sounds. *Acta Psychologica, 146,* 73–83. http://dx.doi.org/10.1016/j.actpsy.2013.12.006

Koch, C. (2004). *The quest for consciousness: A neurobiological approach*. Denver, CO: Roberts and Co.

Koivisto, M., Lähteenmäki, M., Sørensen, T. A., Vangkilde, S., Overgaard, M., & Revonsuo, A. (2008). The earliest electrophysiological correlate of visual awareness? *Brain and Cognition, 66,* 91–103. http://dx.doi.org/10.1016/j.bandc.2007.05.010

Kouider, S., & Dehaene, S. (2009). Subliminal number priming within and across the visual and auditory modalities. *Experimental Psychology, 56,* 418–433. http://dx.doi.org/10.1027/1618-3169.56.6.418

Lähteenmäki, M., Hyönä, J., Koivisto, M., & Nummenmaa, L. (2015). Affective processing requires awareness. *Journal of Experimental Psychology: General, 144,* 339–365. http://dx.doi.org/10.1037/xge0000040

Lamme, V. A. F. (2006). Towards a true neural stance on consciousness. *Trends in Cognitive Sciences, 10,* 494–501. http://dx.doi.org/10.1016/j.tics.2006.09.001

Larson, C. L., Schaefer, H. S., Siegle, G. J., Jackson, C. A. B., Anderle, M. J., & Davidson, R. J. (2006). Fear is fast in phobic individuals: Amygdala activation in response to fear-relevant stimuli. *Biological Psychiatry, 60,* 410–417. http://dx.doi.org/10.1016/j.biopsych.2006.03.079

LeDoux, J. (1998). *The emotional brain: The mysterious underpinnings of emotional life*. New York, NY: Simon & Schuster.

LeDoux, J. E., Sakaguchi, A., & Reis, D. J. (1984). Subcortical efferent projections of the medial geniculate nucleus mediate emotional responses conditioned to acoustic stimuli. *The Journal of Neuroscience, 4,* 683–698.

Liddell, B. J., Williams, L. M., Rathjen, J., Shevrin, H., & Gordon, E. (2004). A temporal dissociation of subliminal versus supraliminal fear perception: An event-related potential study. *Journal of Cognitive Neuroscience, 16,* 479–486. http://dx.doi.org/10.1162/089892904322926809

Lundqvist, D., Flykt, A., & Öhman, A. (1998). *The Karolinska directed emotional faces (KDEF)* [CD-ROM]. Solna, Sweden: Department of Clinical Neuroscience, Psychology Section, Karolinska Institutet.

Macmillan, N. A., & Creelman, C. D. (2004). *Detection theory: A user's guide*. New York, NY: Psychology Press.

Milner, A. D., Goodale, M. A., & Vingrys, A. J. (2006). *The visual brain in action* (Vol. 2). Oxford, United Kingdom: Oxford University Press. http://dx.doi.org/10.1093/acprof:oso/9780198524724.001.0001

Moors, A., & De Houwer, J. (2006). Automaticity: A theoretical and conceptual analysis. *Psychological Bulletin, 132,* 297–326. http://dx.doi.org/10.1037/0033-2909.132.2.297

Murphy, S. T., & Zajonc, R. B. (1993). Affect, cognition, and awareness: Affective priming with optimal and suboptimal stimulus exposures. *Journal of Personality and Social Psychology, 64,* 723–739. http://dx.doi.org/10.1037/0022-3514.64.5.723

Naccache, L., Blandin, E., & Dehaene, S. (2002). Unconscious masked priming depends on temporal attention. *Psychological Science, 13,* 416–424. http://dx.doi.org/10.1111/1467-9280.00474

Nomura, M., Ohira, H., Haneda, K., Iidaka, T., Sadato, N., Okada, T., & Yonekura, Y. (2004). Functional association of the amygdala and ventral prefrontal cortex during cognitive evaluation of facial expressions primed by masked angry faces: An event-related fMRI study. *NeuroImage, 21,* 352–363. http://dx.doi.org/10.1016/j.neuroimage.2003.09.021

Nummenmaa, L., Hyönä, J., & Calvo, M. G. (2010). Semantic categorization precedes affective evaluation of visual scenes. *Journal of Experimental Psychology: General, 139,* 222–246. http://dx.doi.org/10.1037/a0018858

Öhman, A., & Mineka, S. (2001). Fears, phobias, and preparedness: Toward an evolved module of fear and fear learning. *Psychological Review, 108,* 483–522. http://dx.doi.org/10.1037/0033-295X.108.3.483

Olsen, J. F., & Suga, N. (1991). Combination-sensitive neurons in the medial geniculate body of the mustached bat: Encoding of relative velocity information. *Journal of Neurophysiology, 65,* 1254–1274.

Özdamar, O., Kraus, N., & Curry, F. (1982). Auditory brain stem and middle latency responses in a patient with cortical deafness. *Electroencephalography and Clinical Neurophysiology, 53,* 224–230. http://dx.doi.org/10.1016/0013-4694(82)90027-X

Pessoa, L. (2005). To what extent are emotional visual stimuli processed without attention and awareness? *Current Opinion in Neurobiology, 15,* 188–196. http://dx.doi.org/10.1016/j.conb.2005.03.002

Pessoa, L. (2013). *The Cognitive-emotional brain: From interactions to integration*. Cambridge, MA: MIT Press. http://dx.doi.org/10.7551/mitpress/9780262019569.001.0001

Pessoa, L., & Adolphs, R. (2010). Emotion processing and the amygdala: From a "low road" to "many roads" of evaluating biological significance. *Nature Reviews Neuroscience, 11,* 773–783. http://dx.doi.org/10.1038/nrn2920

Pessoa, L., Japee, S., Sturman, D., & Ungerleider, L. G. (2006). Target visibility and visual awareness modulate amygdala responses to fearful faces. *Cerebral Cortex, 16,* 366–375. http://dx.doi.org/10.1093/cercor/bhi115

Pessoa, L., Japee, S., & Ungerleider, L. G. (2005). Visual awareness and the detection of fearful faces. *Emotion, 5,* 243–247. http://dx.doi.org/10.1037/1528-3542.5.2.243

Phelps, E. A., & LeDoux, J. E. (2005). Contributions of the amygdala to emotion processing: From animal models to human behavior. *Neuron, 48,* 175–187. http://dx.doi.org/10.1016/j.neuron.2005.09.025

Phillips, M. L., Williams, L. M., Heining, M., Herba, C. M., Russell, T., Andrew, C., . . . Gray, J. A. (2004). Differential neural responses to overt and covert presentations of facial expressions of fear and disgust. *NeuroImage, 21,* 1484–1496. http://dx.doi.org/10.1016/j.neuroimage.2003.12.013

Quirk, G. J., Repa, C., & LeDoux, J. E. (1995). Fear conditioning enhances short-latency auditory responses of lateral amygdala neurons: Parallel recordings in the freely behaving rat. *Neuron, 15,* 1029–1039. http://dx.doi.org/10.1016/0896-6273(95)90092-6

Ramsøy, T. Z., & Overgaard, M. (2004). Introspection and subliminal perception. *Phenomenology and the Cognitive Sciences, 3,* 1–23. http://dx.doi.org/10.1023/B:PHEN.0000041900.30172.e8

Sauter, D. A. (2007). *An investigation into vocal expressions of emotions: The roles of valence, culture, and acoustic factors*. London, United Kingdom: University of London.

Sauter, D. A., Eisner, F., Ekman, P., & Scott, S. K. (2010). Cross-cultural recognition of basic emotions through nonverbal emotional vocalizations. *Proceedings of the National Academy of Sciences of the United States of America, 107,* 2408–2412. http://dx.doi.org/10.1073/pnas.0908239106

Schafe, G. E., & LeDoux, J. E. (2000). Memory consolidation of auditory pavlovian fear conditioning requires protein synthesis and protein kinase A in the amygdala. *The Journal of Neuroscience, 20,* RC96.

Scherer, L. D., & Larsen, R. J. (2011). Cross-modal evaluative priming: Emotional sounds influence the processing of emotion words. *Emotion, 11,* 203–208. http://dx.doi.org/10.1037/a0022588

Scott, S. K. (2005). Auditory processing: Speech, space and auditory objects. *Current Opinion in Neurobiology, 15,* 197–201. http://dx.doi.org/10.1016/j.conb.2005.03.009

Scott, S. K., Young, A. W., Calder, A. J., Hellawell, D. J., Aggleton, J. P., & Johnson, M. (1997). Impaired auditory recognition of fear and anger following bilateral amygdala lesions. *Nature, 385,* 254–257. http://dx.doi.org/10.1038/385254a0

Stevenage, S. V., Hale, S., Morgan, Y., & Neil, G. J. (2014). Recognition by association: Within- and cross-modality associative priming with faces and voices. *British Journal of Psychology, 105,* 1–16. http://dx.doi.org/10.1111/bjop.12011

Storbeck, J., Robinson, M. D., & McCourt, M. E. (2006). Semantic processing precedes affect retrieval: The neurological case for cognitive primacy in visual processing. *Review of General Psychology, 10,* 41–55. http://dx.doi.org/10.1037/1089-2680.10.1.41

Sweeny, T. D., Grabowecky, M., Suzuki, S., & Paller, K. A. (2009). Long-lasting effects of subliminal affective priming from facial expressions. *Consciousness and Cognition, 18,* 929–938. http://dx.doi.org/10.1016/j.concog.2009.07.011

Tabossi, P. (1996). Cross-modal semantic priming. *Language and Cognitive Processes, 11,* 569–576. http://dx.doi.org/10.1080/016909696386953

Tamietto, M., & de Gelder, B. (2010). Neural bases of the non-conscious perception of emotional signals. *Nature Reviews Neuroscience, 11,* 697–709. http://dx.doi.org/10.1038/nrn2889

Tong, F. (2003). Primary visual cortex and visual awareness. *Nature Reviews Neuroscience, 4,* 219–229. http://dx.doi.org/10.1038/nrn1055

Wiegand, K., & Gutschalk, A. (2012). Correlates of perceptual awareness in human primary auditory cortex revealed by an informational masking experiment. *NeuroImage, 61,* 62–69. http://dx.doi.org/10.1016/j.neuroimage.2012.02.067

Williams, L. M., Liddell, B. J., Kemp, A. H., Bryant, R. A., Meares, R. A., Peduto, A. S., & Gordon, E. (2006). Amygdala-prefrontal dissociation of subliminal and supraliminal fear. *Human Brain Mapping, 27,* 652–661. http://dx.doi.org/10.1002/hbm.20208

Williams, L. M., Liddell, B. J., Rathjen, J., Brown, K. J., Gray, J., Phillips, M., . . . Gordon, E. (2004). Mapping the time course of nonconscious and conscious perception of fear: An integration of central and peripheral measures. *Human Brain Mapping, 21,* 64–74. http://dx.doi.org/10.1002/hbm.10154

Young, A. W., Hellawell, D., & De Haan, E. H. (1988). Cross-domain semantic priming in normal subjects and a prosopagnosic patient. *The Quarterly Journal of Experimental Psychology Section A, 40,* 561–580. http://dx.doi.org/10.1080/02724988843000087

Zajonc, R. B. (1980). Feeling and thinking: Preferences need no inferences. *American Psychologist, 35,* 151–175. http://dx.doi.org/10.1037/0003-066X.35.2.151

Zajonc, R. B. (2000). Feeling and thinking: Closing the debate over the independence of affect. In J. P. Forgas (Ed.), *Feeling and thinking: The role of affect in social cognition* (pp. 31–58). New York, NY: Cambridge University Press.

Zald, D. H. (2003). The human amygdala and the emotional evaluation of sensory stimuli. *Brain Research Brain Research Reviews, 41,* 88–123. http://dx.doi.org/10.1016/S0165-0173(02)00248-5

Received July 16, 2015
Revision received May 12, 2017
Accepted October 3, 2017 ■